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NATURAL ENVIRONMENTAL EFFECTS IN MILITARY MODELS AND SIMULATIONS: PART III—AN ANALYSIS OF REQUIREMENTS VERSUS CAPABILITIES

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13. ABSTRACT *(Maximum 200 words)*
The Defense Modeling and Simulation Office has sponsored the Environmental Effects for Distributed Interactive Simulation (E^2DIS) Project, which is composed of eight tasks including the Survey Task. The Survey Task had three objectives: to develop a baseline of the Military Services' current requirements for incorporation of the atmosphere and near space environment and their effects in military models and simulations (the Requirements Survey), to identify atmospheric and near-space-environment models and databases and environmental effects models and databases that are currently available from the services (the Capabilities Survey), and to compare the results from both survey efforts and make appropriate recommendations.

This report, Part III of a three-part series, describes the results of a comparative analysis of the two surveys, whose results are reported in Part I (the Requirements Survey) and Part II (the Capabilities Survey). The analysis focuses on the eight most-needed types of environmental data, as determined from the Requirements Survey, and shows that the capabilities for providing these data, especially at high fidelity, are deficient. Requirements and capabilities are compared in terms of their horizontal, vertical, and temporal fidelity. Capabilities are deficient if they satisfy less than 75 percent of the requirements. The most significant deficiencies are found in models and databases of aerosols, fog, humidity, and visibility.

14. SUBJECT TERMS
Capabilities Survey, atmospheric effects, Defense Modeling and Simulation Office (DMSO), Environmental Effects for Distributed Interactive Simulation (E^2DIS), Military Services, modeling and simulation (M&S), natural environment, near-space-environment effects, Requirements Survey

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LIST OF ACRONYMS

DIS	Distributed Interactive Simulation
DMSO	Defense Modeling and Simulation Office
DoD	Department of Defense
E^2DIS	Environmental Effects for Distributed Interactive Simulation
M&S	modeling and simulation
QBE	Query By Example
STC	Science and Technology Corporation

EXECUTIVE SUMMARY

During the past few years, there has been growing interest in the Department of Defense (DoD) regarding modeling and simulation (M&S) activities. Leaders in the DoD share a special interest in ensuring that military models and simulations are both realistic and relevant. One technical area that has received considerable emphasis is the natural environment—the terrain, atmosphere, ocean, and space environment. The Defense Modeling and Simulation Office (DMSO), in particular, has been a leader in this regard by sponsoring and funding several projects that are seeking to improve M&S efforts by appropriate incorporation of the natural environment for a variety of military M&S applications.

The DMSO sponsored the Environmental Effects for Distributed Interactive Simulation (E^2DIS) Project. The purpose of the E^2DIS Project is to provide a system that shall incorporate appropriate fidelity physics of the environment and environmental effects seamlessly into distributed simulations using Distributed Interactive Simulation (DIS) standards. This multi-agency project includes the efforts of scientists primarily from the research laboratories of the Military Services. The E^2DIS Project consisted of eight tasks, including the Survey Task. The survey was conducted by a team designed to ensure tri-service coordination. The lead service laboratory for the Survey Team is the Air Force Phillips Laboratory, assisted by the Army Research Laboratory and the Naval Research Laboratory.

The E^2DIS Project's Survey Task was established in part to develop a baseline of the Military Services current requirements for incorporating the atmosphere and near space environment and their effects in military models and simulations. This effort was the Survey Team's first task assignment, routinely called the "Requirements Survey." In addition, the Team was charged with identifying models and databases on the atmosphere, near space environment, and their effects, that are currently available from the Services. This second effort has been known as the "Capabilities Survey." The third assigned task was to compare the results from both survey efforts and make appropriate recommendations based on an analysis of the results of the comparison. Another purpose of the Survey Task has been in a support role: to provide the E^2DIS Project-level management with information gleaned during the two survey efforts for their use in better guiding the project to meet the needs of the sponsor, the DMSO, and the Military Services M&S community.

This report, the third in a three-part series, documents the assessment of a comparison of some results of the two surveys. The Requirements Survey and the Capabilities Survey are documented in two complementary reports: Piwowar et al. (1996) and Burgeson et al. (1996).

The Survey Team identified task drivers for the surveys, developed an execution plan for accomplishing these tasks, and implemented that plan. The major task drivers for the Requirements and Capabilities Surveys were (1) the approach to surveying environmental capabilities, (2) the critical environmental factors for Military Services models and simulations, and (3) the value to the warfighter.

The Survey Team analyzed both the Requirements Survey data (from 74 DoD M&S efforts) and the Capabilities Survey data (from the 152 DoD environmental models and databases) contained in their respective databases and in this report presents the aggregated results. This quantitative analysis not only provides technical details on the comparison between current capabilities for atmospheric and near space environment in environmental models and databases, and the requirements for them by the DoD M&S community, it unambiguously points out needed capabilities. The analysis conducted by the Survey Team identifies several interesting findings regarding the environmental data needed most by the DoD M&S community. These most-needed atmospheric data types (aerosols, clouds, fog, humidity, precipitation, temperature, visibility, and wind) are discussed in Piwowar et al. (1996).

In general, environmental capabilities match reasonably well with M&S environmental requirements; however, those requirements at the highest fidelity range are seldom matched by capabilities. The fidelity requirements range over a spectrum of several orders of magnitude, while fidelity capabilities tend to cluster within portions of the range spectrum, leaving gaps of unsatisfied requirements. These and other results of the analysis of the comparison between requirements and capabilities are discussed in detail in Section 3 of this report.

FOREWORD

Science and Technology Corporation (STC) is pleased to submit this report, the third in a series of three, "Natural Environmental Effects in Military Models and Simulations: Part III—An Analysis of Requirements versus Capabilities," written by Mr. John C. Burgeson, Mr. Thomas M. Piwowar, and Dr. Paul D. Try. Surveys to obtain the needed data were developed and conducted under the guidance of the Military Services representatives of the Environmental Effects for Distributed Interactive Simulation (E^2DIS) Survey Team: Mr. Donald Grantham (Lead), Air Force Phillips Laboratory, Hanscom Air Force Base, Massachusetts; Mr. Sam Brand, Naval Research Laboratory, Monterey, California; and Dr. Alan Wetmore, Army Research Laboratory, White Sands Missile Range, New Mexico. The survey team, consisting of the authors and the Service representatives, wishes to extend its thanks to Dr. Harry Heckathorn, the E^2DIS Program Manager, who assisted in guiding the survey effort.

1. INTRODUCTION

This section briefly summarizes the motivation for and limitations of the environmental surveys. More detail is contained in Piwowar et al. (1996).

1.1 BACKGROUND

Concerned that the Military Services modeling and simulation (M&S) efforts were not rigorously accounting for the effects of the natural environment, in Fiscal Year 1993 the Defense Modeling and Simulation Office (DMSO) initiated the Environmental Effects for Distributed Interactive Simulation (E^2DIS) Project (Heckathorn, 1994; Naval Research Laboratory, 1994, 1995). This multi-agency project under the management lead of the Naval Research Laboratory, Washington, DC, includes scientists from research laboratories of the Military Services. The E^2DIS Project is composed of eight tasks, one of which is the Survey Task. The lead service laboratory for the E^2DIS Project Survey Task was the U.S. Air Force Phillips Laboratory, Geophysics Directorate, Hanscom Air Force Base, Massachusetts. Army and Navy scientists from the Army Research Laboratory, Battlefield Environment Directorate, Adelphi, Maryland, and from the Naval Research Laboratory, Marine Meteorology Division, Monterey, California, respectively, assisted Phillips Laboratory in the Survey Task.

1.2 PURPOSE

The E^2DIS Project Survey Task was initiated to establish a baseline for the current requirements for incorporating data on the atmosphere and near space environment as well as the effects of these natural environments into military models and simulations. The Survey Task effort was also charged with identifying potential future requirements. Another purpose of the surveys was to provide information to E^2DIS Project-level management personnel for their use in better guiding the project to meet the needs of the sponsor, the DMSO, and the Military Services M&S community.

A priori, the E^2DIS Project assumed that there might be some shortfalls or deficiencies in incorporating the natural environment. Therefore, the Survey Task was assigned the additional responsibilities of (1) identifying and cataloging environmental models and databases that might be useful in more realistically representing the atmosphere and near space environment; and (2) assessing the capabilities of these environmental models versus the requirements for incorporating the atmosphere and near space environment in military models and simulations. This report (Part III of the three-part series of reports) documents the analysis of environmental requirements versus capabilities, as tasked by the E^2DIS

Project Survey, in terms of fidelity. Two complementary reports present the results of the Department of Defense (DoD) modeling and simulation environmental requirements baselining (Piwowar et al., 1996) and environmental capabilities assessment efforts (Burgeson et al., 1996).

1.3 SCOPE

One of the first key steps for any project or task is to determine the scope, or constraints, of the effort desired. The E^2DIS Project Survey Team concluded early on that the focus of its efforts should be directed toward the Military Services M&S and environmental modeling and database activities, as opposed to those of the entire DoD. For the technical scope of its effort, the Survey Team was specifically assigned to focus on the atmosphere and near space environment only.

2. SURVEY STRATEGY

The E^{2}DIS Project Survey Team determined that, prior to executing its task, critical planning was essential to achieving success with the survey efforts. During the planning phase, a basic approach was identified, discussed, and agreed upon. This approach included three fundamental components: (1) identification of key task "drivers"; (2) development of an execution plan for the surveys; and (3) implementation of the plan and other associated task efforts.

2.1 TASK DRIVERS

For any task, there are certain key factors, or drivers, that dominate how the task is performed. Early recognition and identification of these factors assist greatly in formulating a reasonable strategy to accomplish the task. For this survey effort, the Survey Team responded to the following task drivers:

- Approach to surveying environmental requirements and capabilities
- Critical environmental factors for military models and simulations
- Value to the warfighter
- Time and funding constraints

These are discussed in the following subsections.

2.1.1 Approach to Surveying Environmental Requirements and Capabilities

The first key driver for the Survey Task was the perceived scope of the Military Services M&S user community and the Military Services environmental database and modeling community. The Survey Team chose a "top-down" approach, as opposed to a "bottom-up" approach, for developing and executing its tasking for the surveys. The top-down approach essentially meant that the Survey Team would initially coordinate any survey plan with the principal point of contact of each of the four Military Services headquarters for atmosphere and near-space-environment models and databases. The bottom-up approach, on the other hand, meant that the Survey Team would pursue numerous, individual points of contact within the Military Services environmental database and modeling community.

The Survey Team selected the top-down approach because such an approach would make the Military Services headquarters aware of the survey and inform the principal points of contact of the intent of the survey well before their subordinate organizations were requested to expend personnel resources in response to survey questions. The Survey Team considered this an important advantage in case difficulties

were experienced in getting responses to survey questions. Although the top-down approach would equate to more time being spent initially in coordinating the Capabilities Survey effort with the Military Services headquarters, the Survey Team's government representatives accepted the minimal scheduled risk in view of the benefits associated with this approach.

2.1.2 Critical Environmental Factors for Military Models and Simulations

The essence of the entire survey effort centered around the identification and defining of the Military Services requirements for incorporation of data on the natural environment—the atmosphere and the near space environment—in the Services M&S activities. In other words, it was necessary to determine the critical environmental factors for each model and simulation. (These factors were reported in Piwowar et al., 1996.) This key task driver dominated the survey effort. It was reflected in the number of questions posed to both the Military Services M&S community and the environmental modeling and database community.

2.1.3 Value to the Warfighter

Another key driver was "value to the warfighter." Warfighters are the ultimate customers for all the Military Services M&S activities, either directly or indirectly, individually or collectively. Their operational experiences in the real world's natural environment provide them with first-hand familiarity of the effects the natural environment can have on their own forces, platforms, weapons, communications, and sensor systems—and the enemy's as well. For a simulation to be realistic, hence valuable, in the eyes of a warfighter, the effects of the natural environment should be properly taken into account. The structure of the Survey Questionnaire (as described in Section 2.2) attempts to use terms familiar to warfighters, as well as terms familiar to the military environmental modeling and database community.

2.1.4 Time and Funding Constraints

Two significant drivers for most tasks are time and funding constraints. The E^2DIS Project's Survey Task was limited to 2 years. Funding constraints limited the amount of personnel resources assigned. These two constraints combined, consequently, to limit the number of M&S efforts pursued.

2.2 EXECUTION PLAN DEVELOPMENT

Given the key task drivers, the Survey Team developed a plan to execute its top-down strategy. This plan included the following major components:

- Soliciting support from the DMSO and key service points of contact
- Developing and testing the Requirements Questionnaire and the Capabilities Questionnaire
- Drafting and coordinating the letters of intent
- Conducting the survey using questionnaires, and telephone and personal interviews with technical experts
- Designing and managing the database
- Analyzing the data from returned questionnaires
- Reporting the results of the analysis

These components are discussed in the following subsections.

2.2.1 The DMSO and Military Services Support

Liaison visits, meetings and briefings were conducted early in the Survey Task's schedule to obtain support in principle from the DMSO and the Military Services. Consistent with the top-down approach, the first such visit was made to the DMSO representative for the E^2DIS Project in August 1993. The DMSO representative provided the Survey Team with an overview of DMSO background, mission, goal, and objectives. This visit indicated that the DMSO was fully supportive of the E^2DIS Project in general and the Survey Task effort in particular.

Visits and meetings with the points of contact of the Army, Navy, Marine Corps, and Air Force staffs were subsequently conducted. All four Services were briefed on the E^2DIS Project and the Project Survey Task effort. They unanimously agreed to the intentions of the survey and affirmed their support for future coordination efforts associated with the Survey Task.

2.2.2 Survey Questionnaire Development and Testing

In parallel with soliciting and garnering support from the DMSO and the four Military Services, development of questionnaires for both the Requirements Survey and the Capabilities Survey began. Since the results of both surveys (i.e., the responses from both the Requirements and Capabilities Questionnaires) would eventually be compared and assessed, the E^2DIS Project's Survey Team decided to structure both questionnaires as similarly as possible. Both questionnaires were divided into two parts: administrative information and technical information. Copies of the questionnaires are provided in the complementary documents (Piwowar et al.,1996; Burgeson et al., 1996).

The administrative information section of the questionnaire requests information on such items as the model or database title, a brief general description of the model or database, and the identity of a technical expert for the model or database, as well as the principal service owner. This type information would be critical in attempting to perform quality control, or followup work, on the responses to the various questions.

The technical information section of the questionnaires is the essence of the surveys. It has seven subsections and three attachments. The seven subsections are

- Critical Environmental Factors
- Status of the Model or Database
- Application of the Model or Database
- Domain of the Environmental Model or Database
- Current Capabilities
- Future Capabilities
- E^2DIS Project Briefing

Using the top-down approach, the Survey Team decided to develop some application questions based upon the modeling and simulation technical structure established by the DMSO in conjunction with the Military Services and the other DoD organizations. That is, the Survey Team sought to construct a framework for the questionnaires that would be relevant and understandable to the DMSO and the Military Services M&S community.

2.2.3 Database

The Survey Team selected the commercial, off-the-shelf *PARADOX for Windows* software program for its database management of the Requirements Survey and the Capabilities Survey sets of data. *PARADOX for Windows* was selected because it provides an efficient, structured method to organize, archive, retrieve, analyze, and display data.

2.2.3.1 Database design

Using the *PARADOX for Windows* program, the Survey Team designed two similar survey databases, one to contain responses to the Requirements Questionnaire and the other to contain responses to the Capabilities Questionnaire. The purpose was to accomplish two important goals:

- Provide a standard methodology by which the large amount of surveyed information could be managed.
- Ensure that the database could be easily understood by anyone familiar with relational databases and be relatively easy to use by someone who was not completely familiar with relational databases.

With these two goals in mind, the Survey Team designed the database such that the questionnaire was associated with (mapped onto) 23 database tables. All 23 database tables corresponded directly to questions in the Requirements Questionnaire and the Capabilities Questionnaire.

2.2.3.2 Database management

The surveys accumulated a formidable amount of data from 216 questionnaires. The Survey Team archived the data by manually entering the data from each of the requirements and capabilities questionnaires received into the appropriate database tables. After sufficient data were entered into these tables, retrieval and analysis of the data began.

The database management system has the capability, called Query By Example (QBE), to ask questions (or queries) about data, explore data in the database, and obtain answers quickly. A query can be a simple question of a single table, or a complex question involving several tables. The QBE provided a powerful means to extract pertinent information from a large amount of data that otherwise would have been very difficult to analyze. The results of queries, called "answer tables," were used as basic input for the Survey Team's analysis reported in Section 3. In addition, database management system "reports" that summarize and display relational information were generated and used by the Team to analyze the acquired data.

2.2.3.3 Database availability

The databases, queries, and reports in the *PARADOX for Windows* format can be obtained from the Phillips Laboratory/Geophysics Directorate Atmospheric Structures Branch (PL/GPAA), 27 Randolph Road, Hanscom Air Force Base, Massachusetts 01731-3010.

2.2.4 Analysis of Data

Querying the databases with QBE in *PARADOX for Windows* was fundamental in planning for the quantitative analysis of the survey technical data. For each response having prescribed multiple choices,

sorted sets of answers would be retrieved. That is, all questionnaire responses of the same choice would be grouped, or sorted, into a set; the number of sorted sets, therefore, would correspond to the number of possible choices for a given request for information. Using *Word Perfect Draw 3.0* as the software graphics program, answer sets were displayed in soft copy for presentation and discussion.

2.2.5 Report of Results

The final major step in the survey plan was to report the results of a comparative analysis of selected portions of the Requirements and Capabilities Surveys data sets. This report, organized in a typical technical-scientific report format, is the third in the series of three reports. Accordingly, the results of the comparative analysis of the Requirements Survey and the Capabilities Survey reported herein are not intended to stand alone; the results are better used in conjunction with the results of the complementary reports on the E^2DIS Project Requirements and Capabilities Surveys.

3. ANALYSIS OF ENVIRONMENTAL DATA REQUIREMENTS VERSUS CAPABILITIES

This section of the report discusses the comparison between the environmental fidelity requirements identified from the 74 DoD simulation models (Piwowar et al., 1996) and the 152 environmental model and database capabilities (Burgeson et al., 1996) documented during the E^2DIS Project Survey Task. Comparisons are depicted in bar graphs that display the fidelity requirements and capabilities of the following types of atmospheric data: aerosols, clouds, fog, humidity, precipitation, temperature, visibility, and wind. (Only those requirements and capabilities whose fidelity is unambiguous were analyzed.) Each of the eight types of data listed above were identified in Piwowar et al. (1996) as those needed most by the DoD M&S community (i.e., primary requirements), and each are shown in graphs of the present requirements and capabilities in terms of their fidelity (horizontal, vertical, and temporal resolution).

The purpose of the indepth analysis presented below is to compare the surveyed environmental fidelity requirements with capabilities in terms of their horizontal, vertical, and temporal scales. The comparative analysis provides a means to accomplish a primary goal of the E^2DIS Survey Task, determine deficiencies of current environmental simulation tools and environmental databases, and point out critically needed new environmental models, codes, and databases.

The discussion concludes with comparisons between the secondary atmospheric data requirements and capabilities to provide these data, and with comparisons between the near-space-environment data requirements and capabilities. The analysis of these two data sets is much less comprehensive than the analysis performed on the most-needed types of data owing to the limited amount of data available for the former analysis.

3.1 OVERVIEW

The overview provides a map to lead the reader through the 24 charts presented in Section 3.2. Each chart depicts one of the eight selected types of atmospheric data. Each type of data is presented in three charts of horizontal, vertical, and temporal fidelity. All individual requirements and capabilities are shown side by side to facilitate a comparison between each requirement and each capability. All charts have a logarithmic vertical (y-) axis to show the wide range fidelity scales. Each vertical bar on the horizontal (x-) axis of a chart represents an individual requirement or capability.

Even a cursory review of the 24 charts leads to the conclusion that, while in general the present environmental capabilities match reasonably well with M&S environmental requirements, requirements at the highest fidelity range are seldom matched by capabilities. Another obvious conclusion is that fidelity requirements range over several orders of magnitude, while fidelity capabilities tend to cluster within portions of the range spectrum and leave gaps of unsatisfied requirements.

A thorough analysis leading to specific conclusions, however, requires that guidelines be established. If some range of fidelity requirements lacks any capability, thereby resulting in a fidelity gap, the capability is obviously deficient within that gap. If less than 75 percent of the total requirements can be matched with capabilities, the overall capability is defined to be deficient. Further, any environmental capability is defined to be a major deficiency if less than half the total fidelity requirements can be matched. For purposes of the descriptive analysis in this report, the fidelity of a capability "matches" the fidelity of a similar requirement if the two fidelities differ by a factor of 3 or less.

Note that a relatively high resolution capability does not necessarily satisfy requirements for much lower (coarser) resolution. For example, a "high resolution" nonhydrostatic model, such as the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS), cannot in principle be run on a theater or larger scale because of computer hardware limitations. Moreover, the high fidelity capability may be inappropriate for the M&S requirement.

With the foregoing guidelines in place, the 24 charts lend themselves to an objective comparative analysis yielding useful results that can stand alone. For example, gaps (along the x-axis) in capabilities point out potential deficiencies. The opposite situation of several similar consecutive capabilities suggests redundancy; however, they were likely developed for other purposes (operational, R&D, etc.) and some could be difficult to use in M&S applications. Interested readers can extend the descriptive analysis provided here by referring to the specific requirements and capabilities discussed in the complementary reports.

Nevertheless, an analysis of greater depth would be required to determine which of the surveyed environmental models, environmental effects models, or databases could best satisfy the environmental requirements for a specific simulation model. The Survey Team believes that such an analysis would be premature in this report given the extent of serious consideration of the environment and environmental effects by the M&S community (see Piwowar et al., 1996). Much more highly focused follow-on surveys

than those conducted under the Survey Task of the E^2DIS Project would be needed to extend significantly the analysis presented here.

Finally, two less comprehensive analyses are presented. The first is an analysis of capabilities versus secondary requirements for atmospheric data by DoD M&S. (Secondary atmospheric data requirements include atmospheric electricity, mixing ratio, refractivity, sea level pressure, static stability, trace gases, transmissivity, wind features, radiative features, smoke, chaff dispersion, dust, contrails, low level dispersion, non-nuclear munitions effects, nuclear detonation effects, and ship exhaust tracks.) The second analysis is on the comparison between near-space-environment data requirements and the capabilities to provide these data. The analysis is less comprehensive because near space data requirements and capabilities represent only a very small fraction of the surveyed environmental requirements and capabilities. Of the 74 unique M&S requirements, only 7 include near space data; of the 152 unique environmental capabilities, only 11 provide near-space-environment related data.

3.2 SELECTED ATMOSPHERIC DATA FIDELITY REQUIREMENTS VERSUS CAPABILITIES

Each of the eight atmospheric variables needed most by the DoD M&S community are analyzed in three charts depicting horizontal, vertical, and temporal fidelity (resolution) requirements and capabilities. Each white vertical bar represents a unique environmental M&S requirement whose fidelity has been specified; each black vertical bar represents a unique environmental capability at its available fidelity. The requirements and capabilities are arranged along the horizontal axis in order of decreasing fidelity from left to right, an ordering that readily shows the match between requirements and capabilities. Even a brief glance would reveal gaps in fidelity capability where requirements are unmatched; a closer look would disclose a major deficient capability. The gaps can be subjectively identified as being within the high-, mid-, or low-fidelity range to classify the range of the deficiency.

As an example, consider Figure 1a in which 15 individual horizontal fidelity requirements for aerosols and five individual capabilities to provide aerosols at specified horizontal fidelity are depicted. Immediately obvious on the vertical axis is the huge range of required fidelity across eight orders of magnitude (from 1 cm to almost 1000 km). An examination along the horizontal axis reveals a major deficiency of capabilities that can satisfy these requirements; only six capabilities match (according to the guidelines established here) the 15 requirements. Note the large gap in capabilities between 100 m and 40 km. The lone fidelity capability at 100 m matches the two fidelity requirements at 100 and 300 m

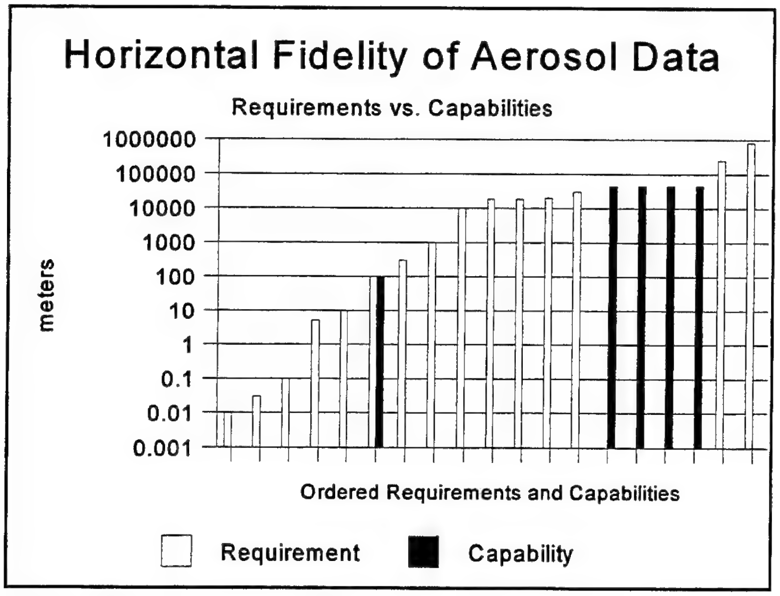

Figure 1a. Comparison between environmental capabilities and M&S requirements for data on the horizontal structure of atmospheric aerosols.

(i.e., the fidelity of the capability is within a factor of 3); similarly, the four fidelity capabilities at 45 km match four fidelity requirements at 20 km.

3.2.1 Aerosol Data Fidelity Requirements and Capabilities

Figure 1a illustrates that no capability matches the five requirements to characterize aerosols at the highest horizontal fidelity range from 1 cm to 10 m because the nearest capability has a horizontal fidelity of 100 m. The fidelity capability gap between 100 m and 45 km contains seven requirements; five of the requirements are within a factor of 3 of the capabilities bordering the gap, and two of the requirements (at 1 and 10 km) are unmatched by capabilities. The two lowest horizontal fidelity requirements are greater than 300 km, which cannot be matched by the capabilities at 45 km. Accordingly, with only 6 of the total of 15 requirements matched by capabilities, a major deficiency exists in the capability to provide aerosols at the required horizontal fidelity. This major deficiency is present in the high-fidelity range (100 m and less), where only one of six requirements is matched, but not in the mid- to low-fidelity range (more than 300 m), where five of nine requirements are matched.

Figure 1b indicates a match between 7 of 14 requirements for characterizing aerosols in the vertical and capabilities. No capabilities exist with higher than 1-m resolution, leaving the four highest fidelity requirements unmatched. Capabilities are also deficient in the fidelity gap between 50 and 800 km, where three requirements cannot be satisfied. Consequently, 50 percent of the overall requirements are matched

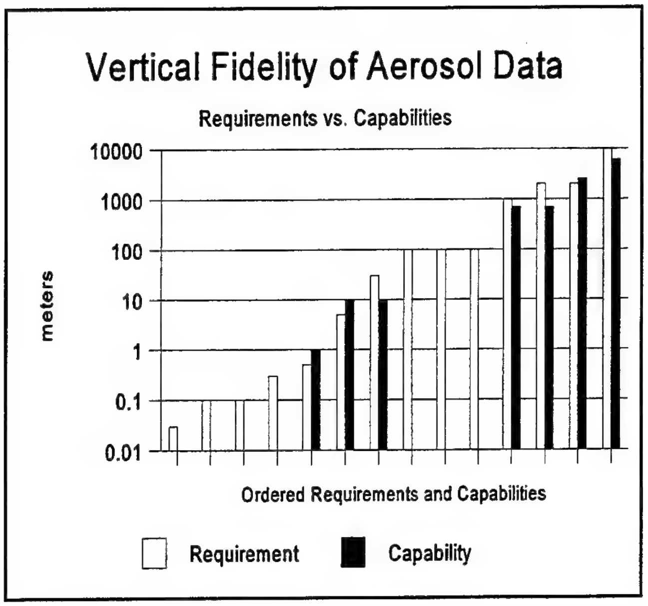

Figure 1b. Comparison between environmental capabilities and M&S requirements for data on the vertical structure of atmospheric aerosols.

by capabilities, establishing an overall deficiency but not a major deficiency. (Recall that if less than 75 percent of the total requirements can be matched with capabilities, the overall capability is defined to be *deficient*. A major deficiency exists if less than 50 percent of the total fidelity requirements can be matched.)

The analysis can be extended further. Based on the range of fidelity on the vertical axis of Figure 1b, requirements between 1 cm and 1 m can be arbitrarily classified high fidelity, requirements between 1 and 100 m mid fidelity, and requirements between 100 m and 10 km low fidelity. Then the high-fidelity capability is a major deficiency because only one of five requirements is matched by capabilities, the mid-fidelity capability is also a major deficiency because three of five requirements are unmatched by capabilities, and the low-fidelity capability matches all requirements. This statement perhaps is an overanalysis of the data, but it does make clear that a major deficiency of fidelity capability exists except for the low-fidelity range, where all four requirements are matched and make the overall capability look better than it is.

Figure 1c illustrates a major deficient capability to match the six requirements to characterize aerosols on a temporal scale less than a minute (high fidelity). Except for the single requirement at 15 min, the eight remaining temporal fidelity requirements, which are on the order of 1 to 3 hr and represent a slight majority of the total temporal requirements for aerosols, are satisfied by present capabilities. Accordingly, the overall capability is classified as deficient.

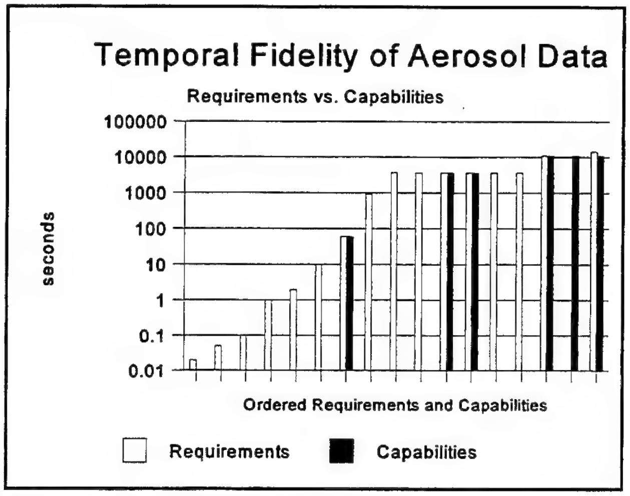

Figure 1c. Comparison between environmental capabilities and M&S requirements for data on the temporal structure of atmospheric aerosols.

3.2.2 Cloud Data Fidelity Requirements and Capabilities

Figure 2a illustrates that the three requirements for clouds at the highest horizontal fidelity (at a resolution of 10 m or less) are unmatched by available capabilities to characterize them; nevertheless, most (11 of 17) requirements for cloud data are matched by an apparent abundance of capabilities. The abundance likely resulted from the large number of operational requirements, not misdirected attempts to satisfy M&S requirements for cloud data. The fidelity requirements at 1000 km could possibly be satisfied from other available data or by inference.

Figure 2b illustrates that 7 of 13 vertical resolution requirements for clouds are matched by capabilities. An abundance of capabilities characterizes clouds at needed fidelity except the mid-range deficiency gap between 1 and 500 m, where there are five unmatched requirements. This mid-range fidelity gap is a major deficiency, although the overall capability is deficient, and needs to be filled by a capability with a vertical resolution of 100 m.

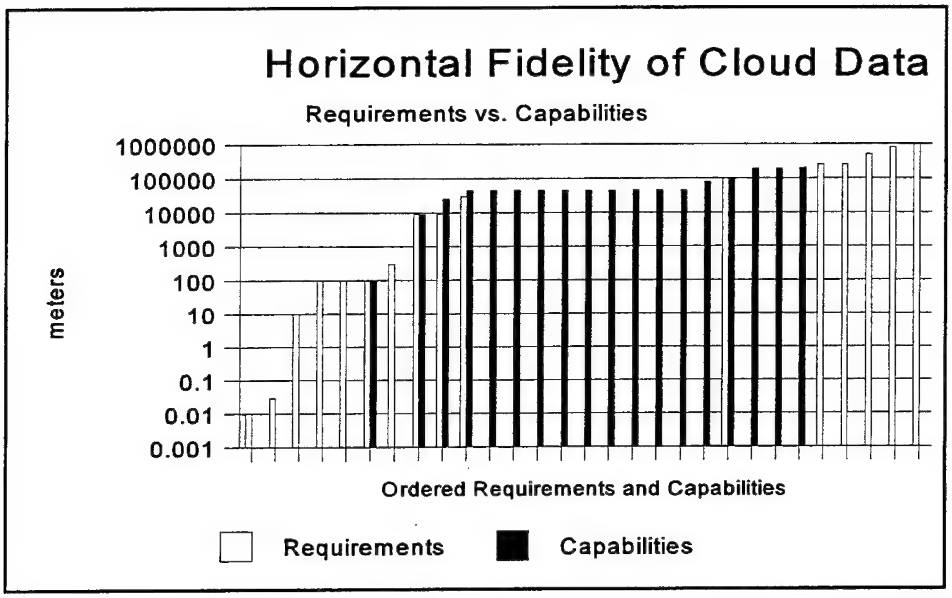

Figure 2a. Comparison between environmental capabilities and M&S requirements for data on the horizontal structure of clouds.

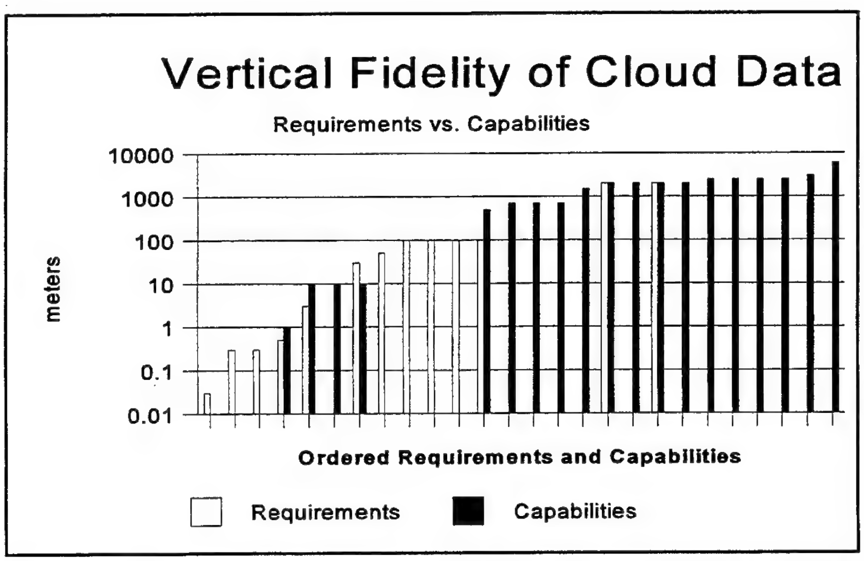

Figure 2b. Comparison between environmental capabilities and M&S requirements for data on the vertical structure of clouds.

Figure 2c depicts capabilities that characterize all required time scales of clouds except for scales less than 10 s, where no capability exists to match the five requirements. Required time scales at 1 hr and greater (the low-fidelity range) are overwhelmed by capabilities except for an outlying requirement at 2 weeks that can probably be inferred from available capabilities. With 6 of 18 requirements unmatched by capabilities, an overall deficiency (a major high-fidelity deficiency) exists.

3.2.3 Fog Data Fidelity Requirements and Capabilities

A major deficiency in the capability to characterize fog at required horizontal fidelity is evident from Figure 3a. Only at the mid range of fidelity (resolution between 10 and 80 km) do capabilities satisfy the four requirements there. The seven high-fidelity (1000 m and less) and four low-fidelity (400 to 1000 km) requirements are unmatched by capabilities. The need for a capability to characterize fog on a horizontal scale of hundreds of meters is apparent.

A major deficiency exists in the vertical fidelity of available capabilities to provide data on fog that match DoD M&S requirements. Figure 3b illustrates the mid-fidelity gap (between 10 and 700 m) in capability to characterize the four fog requirements at 100-m vertical resolution. With those and the two unmatched requirements at less than 1-m vertical resolution, only 4 of 10 requirements are matched by capabilities. The gap in vertical resolution capability to characterize fog needs to be filled by a 100-m capability because 50 percent of the requirements fall within the gap. The requirements for fog data with a vertical resolution of 30 and 50 cm are probably less significant.

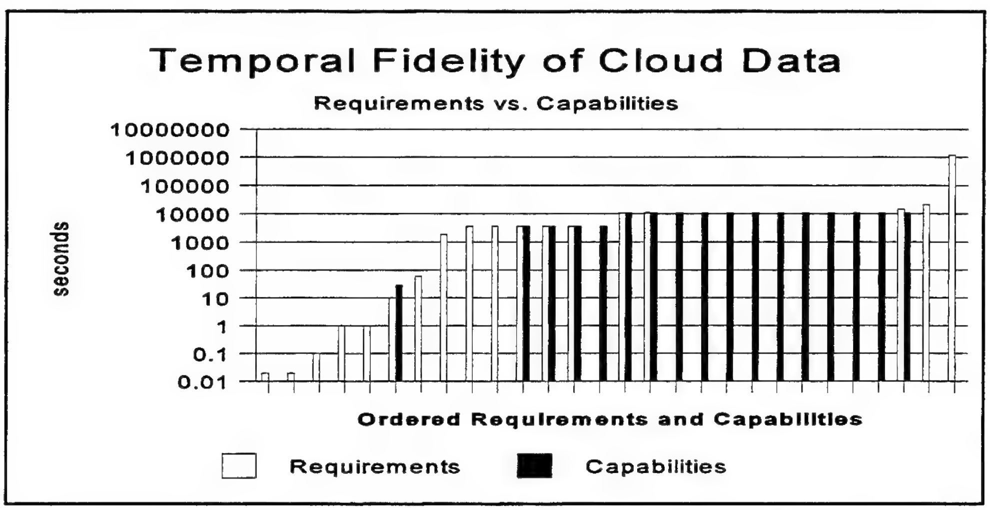

Figure 2c. Comparison between temporal environmental capabilities and M&S requirements for data on clouds.

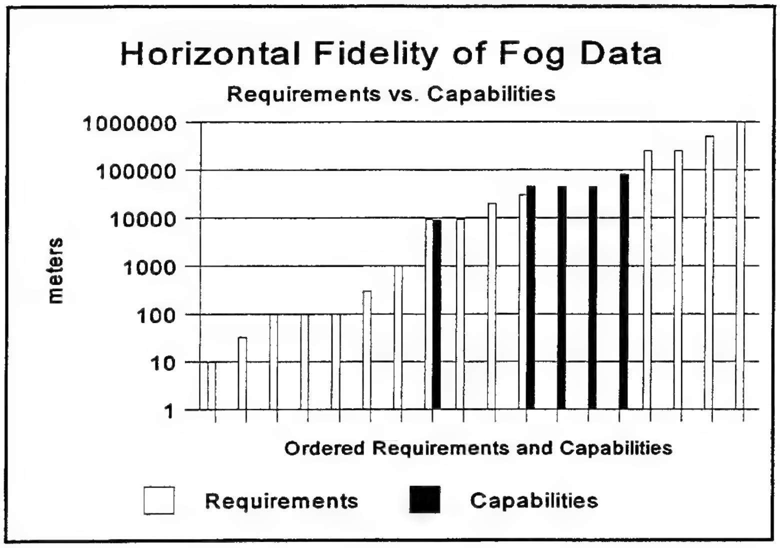

Figure 3a. Comparison between environmental capabilities and M&S requirements for data on the horizontal structure of fog.

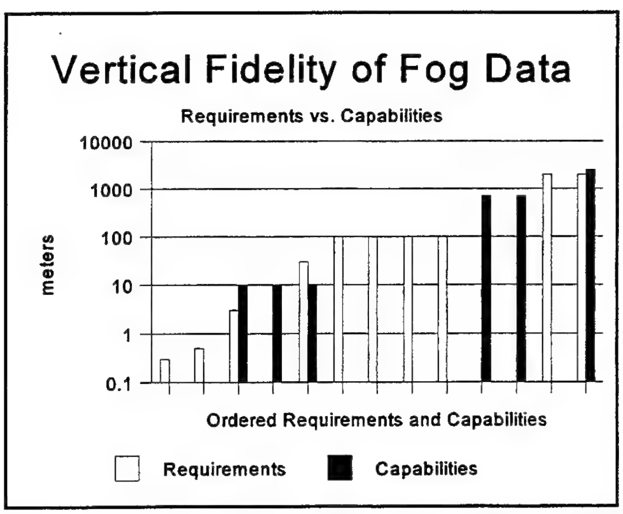

Figure 3b. Comparison between environmental capabilities and M&S requirements for data on the vertical structure of fog.

Figure 3c illustrates that sufficient capabilities exist to characterize fog for the required time fidelity. Except for the two requirements at a resolution of 10 s, the match of capabilities with requirements is remarkably close.

3.2.4 Humidity Data Fidelity Requirements and Capabilities

Figure 4a illustrates a major deficiency in capabilities to characterize humidity at the required horizontal fidelity. No capabilities match the seven high-fidelity requirements at a horizontal resolution of 1000 m or less. The remaining six requirements are at a low fidelity (resolution of 10 km or more) and are matched with seven capabilities.

Figure 4b illustrates a mid-range gap (between 10- and 600-m resolution) in fidelity capabilities to characterize humidity in the vertical range. The gap contains more than 50 percent of the total number of M&S requirements (6 of 10), 5 for 100-m resolution and 1 for 50-m resolution. This is an atypical major deficiency; more than sufficient capabilities exist at both ends of the fidelity range, but most requirements are located within the mid range of the fidelity spectrum. A humidity capability with a vertical resolution of 100 m is needed to eliminate the deficiency.

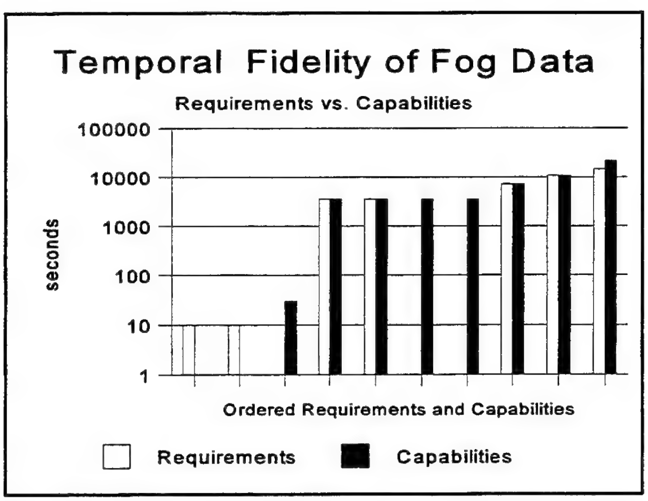

Figure 3c. Comparison between environmental capabilities and M&S requirements for data on the temporal fidelity of fog.

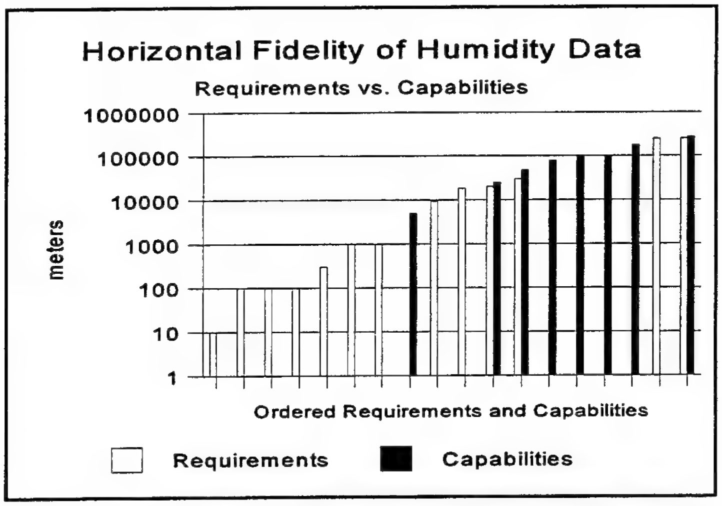

Figure 4a. Comparison between environmental capabilities and M&S requirements for data on the horizontal structure of humidity.

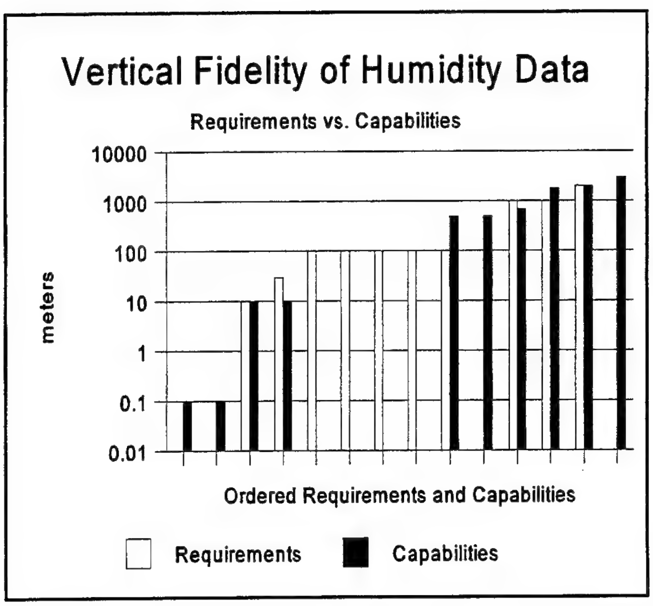

Figure 4b. Comparison between environmental capabilities and M&S requirements for data on the vertical structure of humidity.

Figure 4c depicts an overall deficiency capability to characterize humidity on needed time scales. The four highest and the lowest fidelity requirements (5 out of 15) cannot be matched by current capabilities. None exist anywhere near the two requirements for 10-s temporal resolution, and the two requirements for 15-min time resolution cannot be approximately satisfied by the 1-hr humidity capability; therefore the high-fidelity capabilities are a major deficiency. A new humidity capability with a fidelity of 15 min would probably be more useful than a 10-s capability. Most requirements, however, are within a time scale of 1 to 3 hr, a range covered by the six available capabilities.

3.2.5 Precipitation Data Fidelity Requirements and Capabilities

Figure 5a illustrates that only one capability (at 100-m resolution) is available to satisfy the nine requirements to characterize precipitation in the high- to mid-fidelity range having a horizontal resolution between 10 cm and 1000 m, and that lone capability matches five requirements. The remaining four fidelity requirements in that range as well as two low-fidelity (lower than 500-km horizontal resolution) requirements are unmatched with capabilities. Therefore, a deficiency exists across the required fidelity range, where 7 requirements (from a total of 19) cannot be satisfied by capabilities, while a good balance exists between requirements and capabilities in the 10–100-km range of fidelity. A capability with a horizontal resolution near 500 m would help fill the gap between 100 m and 8 km.

Figure 5b makes clear that most requirements for characterizing precipitation at the needed vertical fidelity can be satisfied by available capabilities. The requirements at both ends of the fidelity range are unlikely candidates for research or database development.

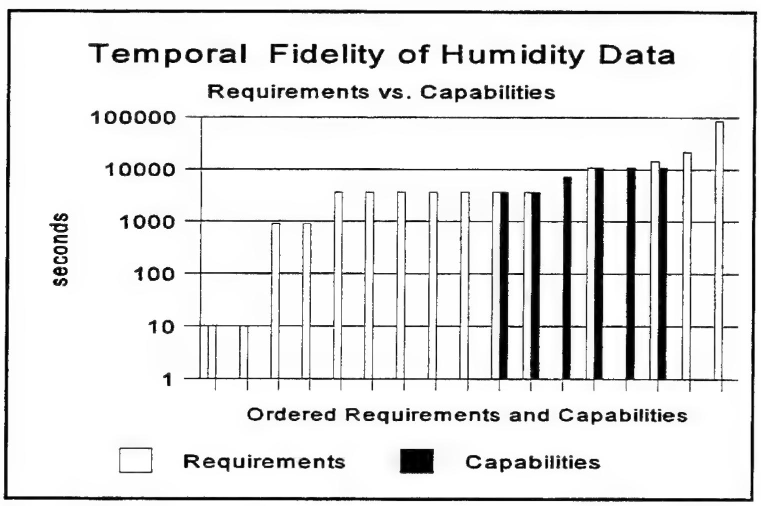

Figure 4c. Comparison between environmental capabilities and M&S requirements for temporal data on humidity.

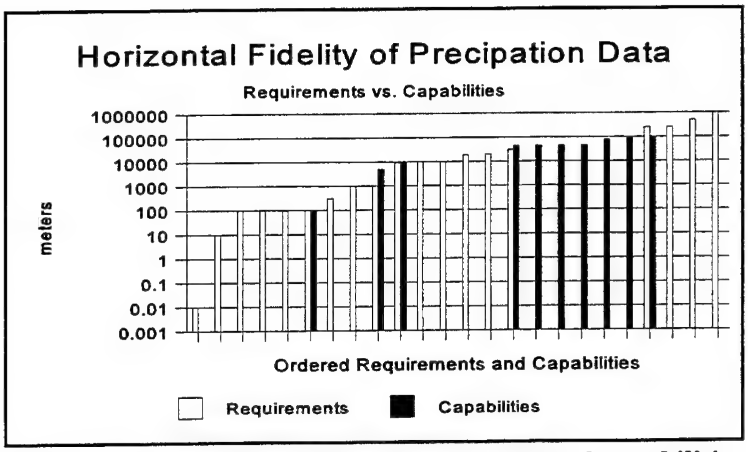

Figure 5a. Comparison between environmental capabilities and M&S requirements for data on the horizontal structure of precipitation.

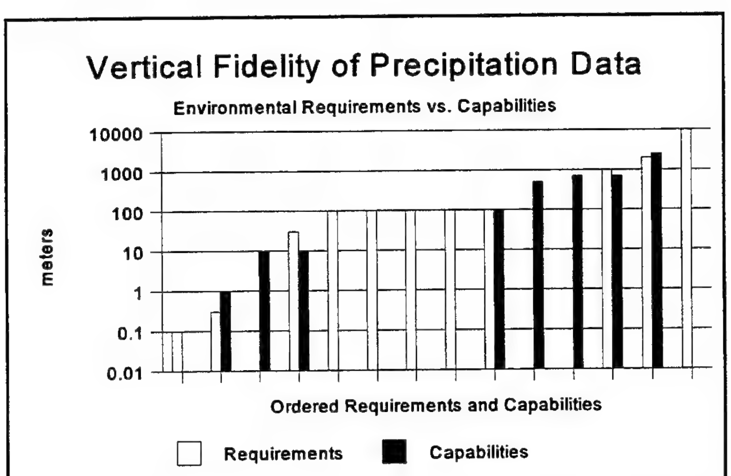

Figure 5b. Comparison between environmental capabilities and M&S requirements for data on the vertical structure of precipitation.

There are six requirements depicted in Figure 5c for characterization of precipitation at high-temporal fidelity (15 min or less) but only one capability with a time resolution of less than 1 hr. That capability has a resolution of 1 min and matches only one of the five high-fidelity requirements; accordingly, a major deficiency of high-fidelity capability exists. It is, however, only an overall deficiency because 9 of the 16 requirements are matched by capabilities. As Figure 5c illustrates, the requirements of the majority are at a lower fidelity (temporal scales of an hour or greater) and they are matched by capabilities. DoD M&S requirements for the characterization of precipitation are matched by available capabilities except at high fidelity.

3.2.6 Temperature Data Fidelity Requirements and Capabilities

Figure 6a illustrates a major high- and mid-range fidelity deficiency: 8 requirements (from a total of 16) characterize temperature at high fidelity (1000 m and less), but no capability exists with horizontal resolution better than 5000 m. At horizontal scales greater than 50 km, however, an excess of several capabilities satisfies the remaining eight requirements. Consequently, an overall deficiency exists, and a high-fidelity capability to characterize temperature on a horizontal scale of about 100 m appears to be needed.

Figure 6b illustrates that most (8 of 13) requirements to characterize temperature at vertical resolutions are matched by available capabilities. The notable exceptions are the two 2-m fidelity requirements that fit near the middle of a gap in fidelity capability between 10 cm and 10 m. With four capabilities surrounding those requirements, however, no further development of vertical temperature models or databases appears to be needed.

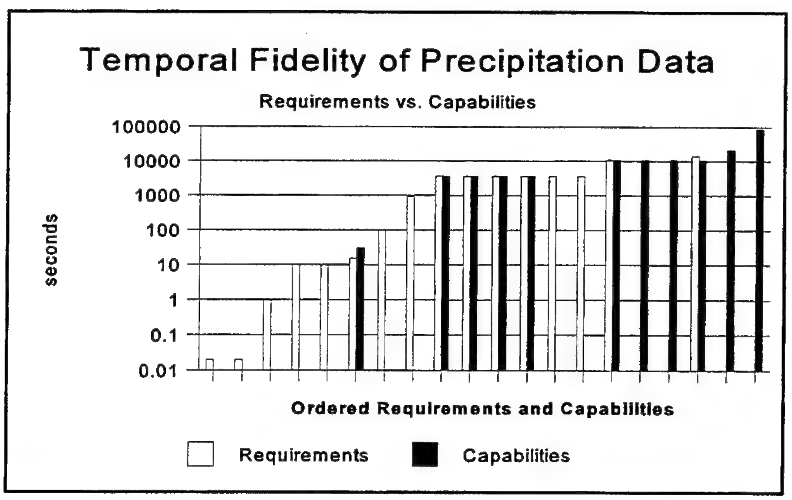

Figure 5c. Comparison between environmental capabilities and M&S requirements for temporal data on precipitation.

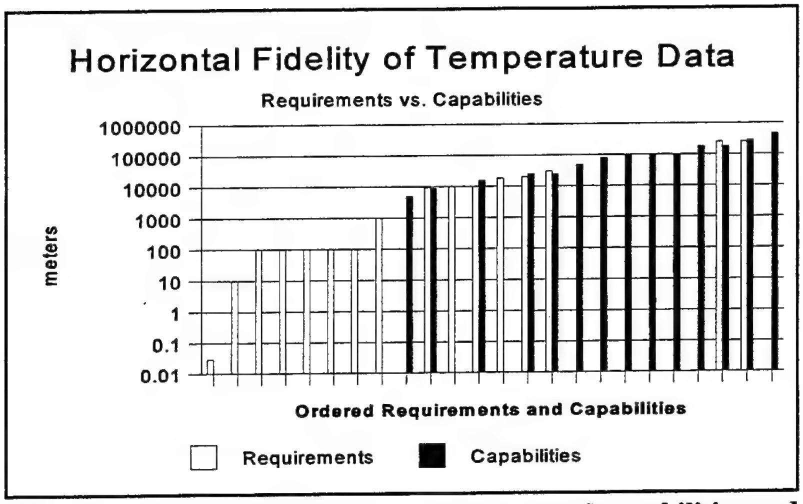

Figure 6a. Comparison between environmental capabilities and M&S requirements for data on the horizontal structure of temperature.

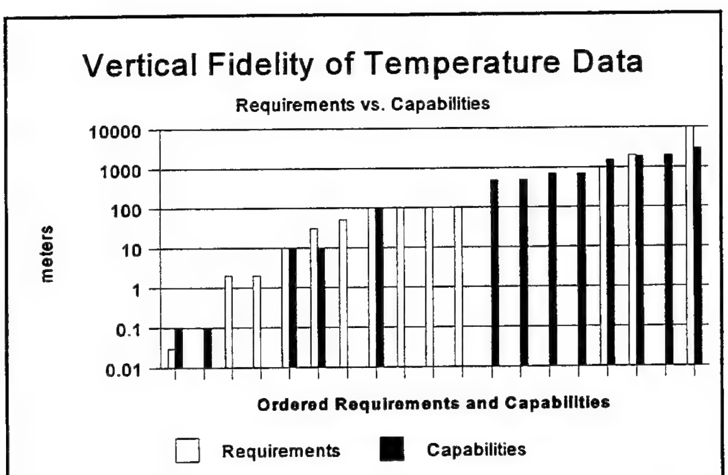

Figure 6b. Comparison between environmental capabilities and M&S requirements for data on the vertical structure of temperature.

Figure 6c depicts a good overall match between requirements to characterize the temporal structure of temperature on time scales and capabilities except at the highest fidelity (0.02 and 1 s). Only one capability exists that has a resolution less than 1 hr; that 30-s capability matches three of the six requirements in the capabilities gap between 0.05 s and 15 min. An abundance of capabilities exist between 1 and 3 hr, the synoptic data time scales.

3.2.7 Visibility Data Fidelity Requirements and Capabilities

With only two capabilities available to characterize visibility with any horizontal fidelity, which is so low that the capabilities satisfy less than a quarter (4 of 17) of the requirements, Figure 7a illustrates an obvious major deficiency. The 12 requirements for visibility data at a resolution at 10 km and less certainly cannot be satisfied by a capability at 60 km. Clearly, development of high-fidelity and mid-fidelity (100 m and 10 km) visibility models and databases are needed.

A similar major deficiency is obvious in Figure 7b, which illustrates that only one capability exists to characterize visibility at any specific vertical resolution. Moreover, the fidelity of that capability is so low that it matches only 3 of the 14 requirements. Clearly, high-fidelity (100-m vertical resolution and higher) visibility data are needed.

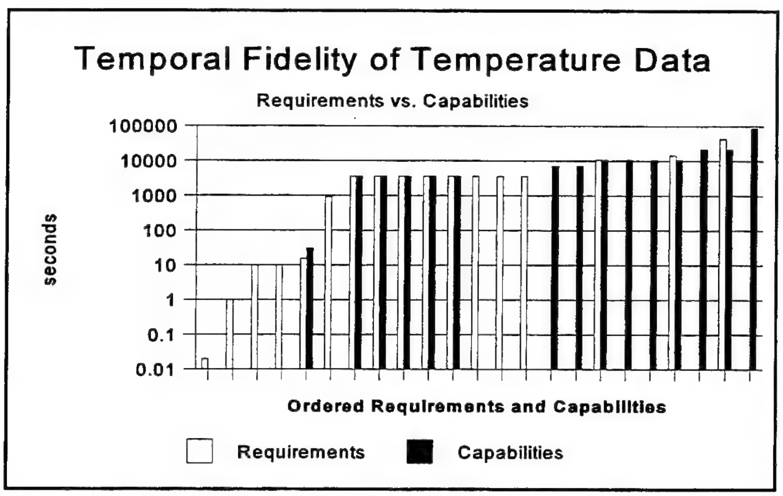

Figure 6c. Comparison between environmental capabilities and M&S requirements for temporal data on temperature.

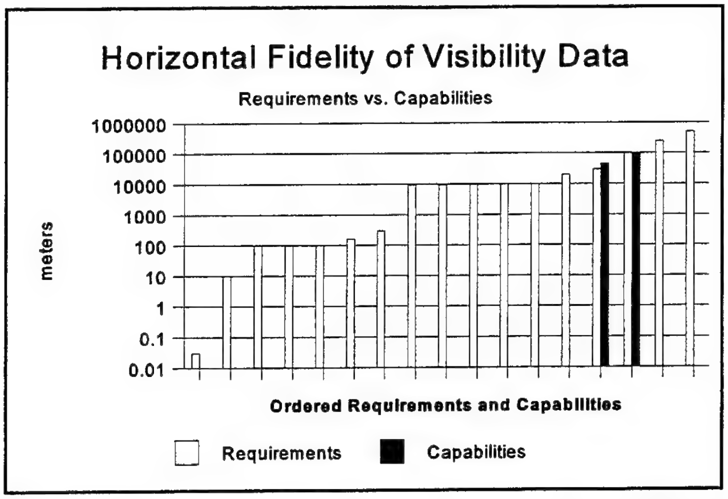

Figure 7a. Comparison between environmental capabilities and M&S requirements for data on the horizontal structure of visibility.

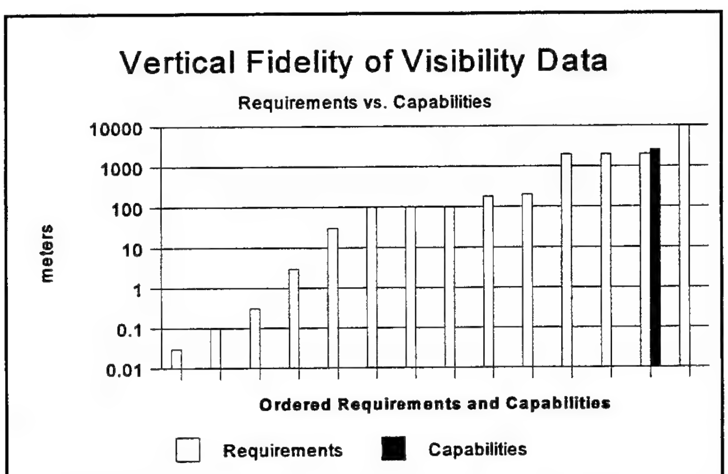

Figure 7b. Comparison between environmental capabilities and M&S requirements for data on the vertical structure of visibility.

Figure 7c illustrates that only three capabilities exist to characterize visibility, none having sufficient temporal fidelity to satisfy requirements on time scales less than 1 hr. Nine high-fidelity requirements have time scales at least 2 orders of magnitude smaller than the best fidelity capability, which is a major deficiency. The 10 remaining requirements (of 19) are matched by capabilities, and the overall capability is deficient. A visibility capability with 10-s resolution is needed. Visibility is the only type of atmospheric data of the eight needed most for the DoD M&S activities whose existing capabilities in both space and time are major deficiencies in the mid- and high-fidelity ranges.

3.2.8 Wind Data Fidelity Requirements and Capabilities

Figure 8a depicts an obvious major deficiency to characterize wind at high horizontal fidelity (resolution of 100 m and less): no capability exists within an order of magnitude that satisfies the eight requirements. At lower fidelity, however, a good balance exists between requirements and capabilities. With 12 of 21 requirements matched by requirements, overall capabilities are deficient. Clearly, an abundance of low-fidelity capabilities exists, while high fidelity wind capabilities need to be developed. The DoD M&S community needs most a wind capability with a 100-m horizontal resolution.

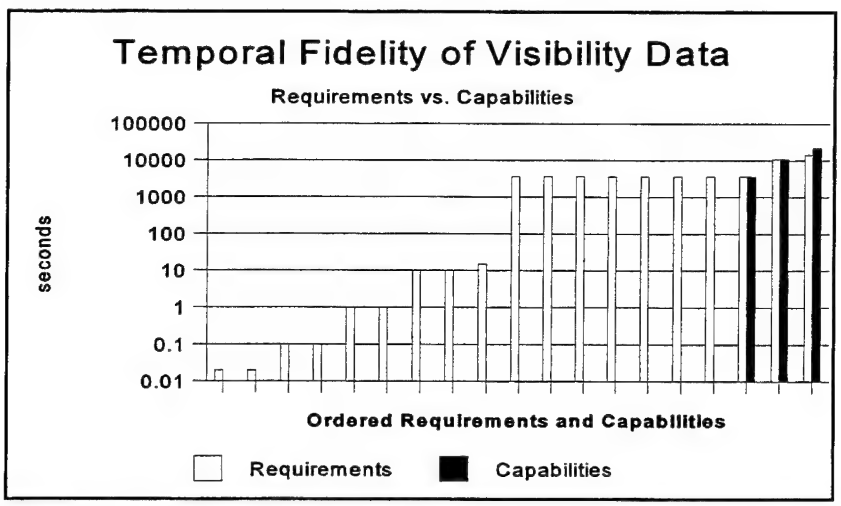

Figure 7c. Comparison between environmental capabilities and M&S requirements for data on the vertical structure of visibility.

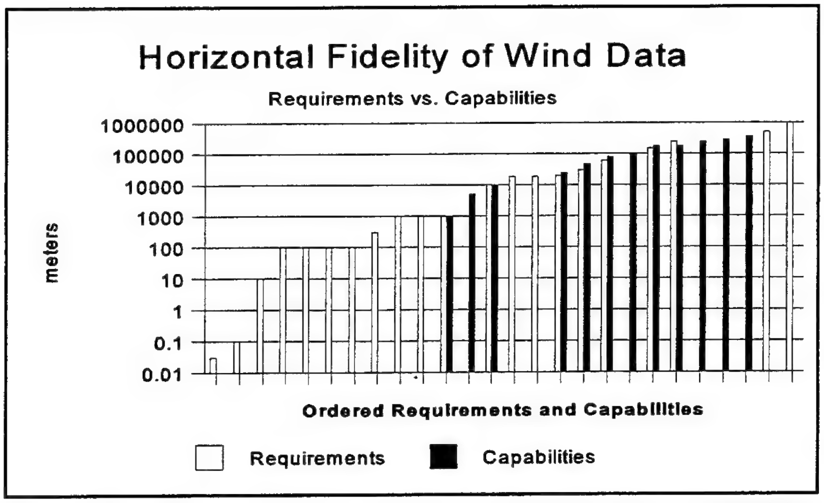

Figure 8a. The comparison between environmental capabilities and M&S requirements for data on the horizontal structure of wind.

There is a good match between requirements to characterize wind within needed ranges of vertical fidelity and available capabilities, as illustrated in Figure 8b. With 12 of 16 requirements matched by capabilities, no deficiency exists; the four unmatched requirements for wind data at a vertical resolution of 5 cm and 10 cm and 10 km are at a fidelity scale where research is unlikely. The requirement at 80 m could probably be satisfied by data surrounding that fidelity.

Figure 8c illustrates that requirements to characterize wind at all time scales greater than 15 s are matched by capabilities. None of the eight high-fidelity (10 s or better resolution) requirements are matched, however, and the lack of high-fidelity capability is a major deficiency, one that could be eliminated with the development of a 5-s wind resolution capability. The high-fidelity requirements account for 25 percent of the total; therefore the overall temporal wind capability is sufficient.

3.3 ENVIRONMENTAL DATA FIDELITY REQUIREMENTS VERSUS CAPABILITIES: OTHER TYPES OF DATA

This subsection completes the analysis of environmental capabilities required for the M&S activities. The requirements discussed below are secondary because relatively few models and simulations need these types of data. These secondary requirements deserve to be documented but with the caveat that the results of this analysis must be regarded as tentative because a small data sample was analyzed. The deficiencies

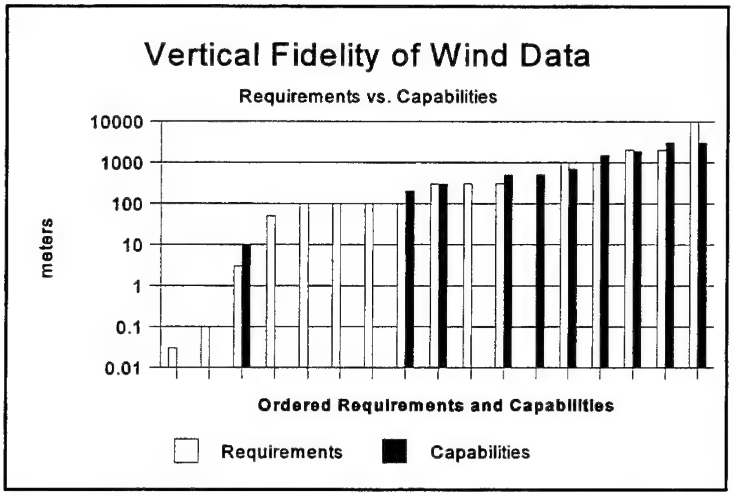

Figure 8b. Comparison between environmental capabilities and M&S requirements for data on the vertical structure of wind.

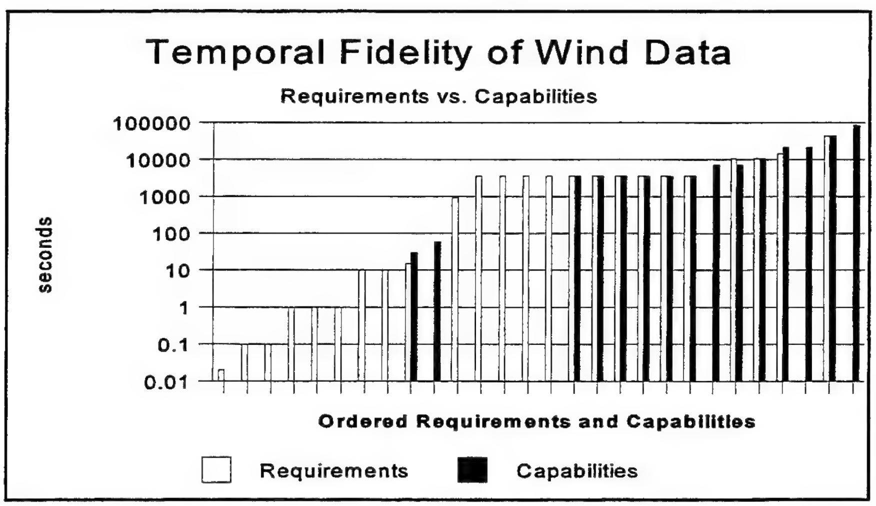

Figure 8c. Comparison between environmental capabilities and M&S requirements for temporal data on wind.

(the data were insufficient to distinguish major deficiencies) are identified by an "X" in Table 1, which follows the descriptive list below.

- Requirements for high horizontal and vertical fidelity dewpoint temperatures are poorly matched by relatively low-fidelity capabilities. The required temporal fidelity, however, matches present capabilities.
- The capability to characterize transmissivity at very high fidelity (1 m and 1 s) apparently overwhelms most requirements, whose fidelity is 2 and 3 orders of magnitude lower.
- The capability to characterize radiative features at high horizontal and vertical fidelity also overwhelms the requirements, while the temporal-fidelity capabilities are a good match for most requirements.
- The capability to characterize wind features at high horizontal and any vertical fidelity, where only one capability exists to satisfy eight requirements, is deficient; however, the temporal capability is sufficient.
- Sea level pressure requirements are well matched by capabilities at most space and temporal scales.
- A poor match is made between horizontal fidelity requirements for smoke and capabilities to characterize smoke; however, the temporal and vertical scales are matched well. With only two capabilities to characterize smoke and both of them at very high horizontal fidelity (1 m), a deficiency to satisfy the eight requirements occurs at much lower fidelity.
- Mixing ratio requirements are well matched by capabilities for all vertical scales but not for high fidelity horizontal and temporal scales.
- Relatively few requirements for atmospheric electricity are observed; the only capability is provided at a point on an hourly basis.
- More individual capabilities for refractivity information are available than requirements observed, although the matching of fidelities is deficient.
- No capabilities are available to match the few requirements for static stability in either the horizontal or vertical fidelity, or at a time fidelity less than 1 hr.
- Few requirements are observed for or capabilities available to provide characterization of trace gases at any fidelity.
- Few requirements are observed for and even fewer capabilities are available to provide the remaining data types (chaff dispersion, combat-generated dust, contrail formation and dispersion, other dispersion, and non-nuclear and nuclear detonation effects. While these requirements are unmatched, they are too few in number to suggest that a significant deficiency exists.

Table 1. Deficiencies of Other Environmental Models and Databases

Secondary Atmospheric Data Type	Other Deficiencies of Fidelity Capability		
	Horizontal	Vertical	Temporal
Dewpoint	X	X	
Transmissivity	X		
Radiative Features	X	X	
Wind Features	X	X	
Smoke	X		
Mixing Ratio	X		X

3.4 A QUALITATIVE COMPARISON BETWEEN NEAR SPACE DATA REQUIREMENTS AND CAPABILITIES

Less than 10 percent of the surveyed M&S efforts need near space data, and less than 10 percent of the surveyed environmental models and databases are capable of providing near space data. Moreover, most of the data fidelity descriptions were incomplete or difficult to interpret in terms of horizontal, vertical, and temporal scales. Consequently, insufficient data exist to analyze fidelity, and the discussion that follows must be regarded as much less definitive than the above analysis of the primary M&S requirements for environmental data and matching capabilities.

As illustrated in Figure 9, the 11 surveyed capabilities provide 17 unique types of near space data. Six capabilities satisfy the five requirements for solar parameters, which are the most-needed types of near space data. No capability was surveyed to provide gravity waves, noctilucent clouds, polar cap absorption, Sporadic E, sudden ionospheric storms, dispersal of flares, formation and dispersion of rocket exhaust, and the effects of non-nuclear and nuclear munition detonation. Three simulation models require at least one of these data types except gravity waves, for which there is neither a requirement nor a capability.

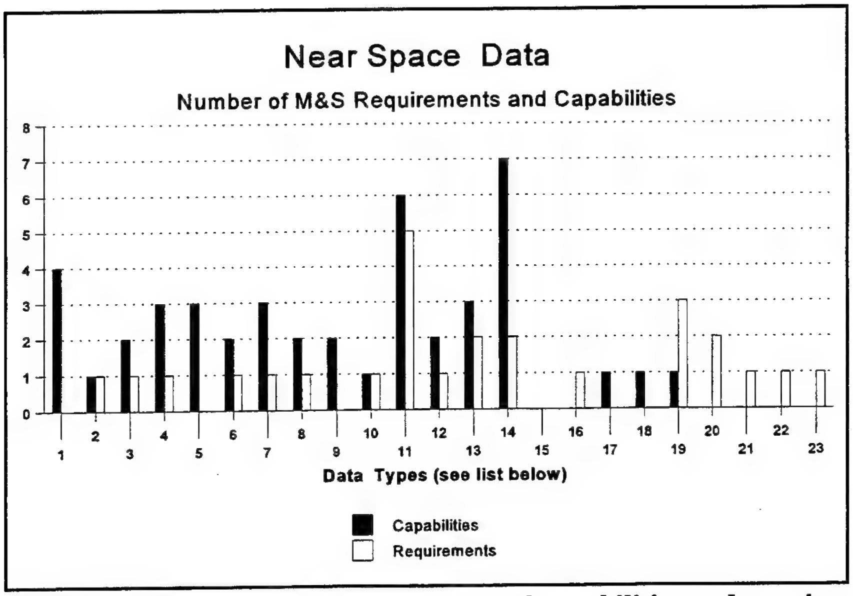

Figure 9. A comparison of environmental capabilities and requirements for near-space-environment data types.

A summary list of the near-space-environment data types is provided below:

1. Auroral Particle Precipitation
2. Cosmic Rays
3. Diffuse Zodiacal Emission
4. Geomagnetic Field
5. Interplanetary Medium
6. Low Energy Plasma Environment
7. Lunar Parameters
8. Meteoroids and Debris
9. Neutral Environment
10. Radio Background Noise
11. Solar Parameters
12. Star and Planetary Position
13. Energetic Particles
14. Geomagnetic Storms
15. Gravity Waves
16. Noctilucent Clouds
17. Polar Cap Absorption
18. Sporadic E
19. Sudden Ionospheric Storms
20. Dispersal of Flares
21. Formation and Dispersal of Rocket Exhaust
22. Munitions Effects (non-nuclear)
23. Nuclear Weapons Detonation Effects

4. SUMMARY

The preceding analysis illustrates and discusses the comparison between the environmental data required most by the DoD M&S community, and the DoD environmental modeling and database community's capability to provide that data at the needed fidelity. A brief glance at the charts in Section 3 strongly suggests the existence of a mismatch between requirements and capabilities. The authors emphasize that the mismatch is not a function of misdirected environmental research and development; environmental models and databases were primarily developed to satisfy DoD operational requirements.

The results of this report could be used to direct environmental research and development efforts towards DoD M&S requirements that appear to be deficient. Toward this end, Section 4.1 highlights the more significant mismatches; they represent high priority areas of needed future environmental model and database development. In Section 4.2 specific conclusions are discussed that draw on these areas of needed development, and in Section 4.3 the recommendations are discussed.

4.1 FINDINGS

The primary purpose of the E^2DIS Survey Task was to assess current capabilities for specifying the atmosphere and near space environment for modeling and simulation at the fidelity needed by the Military Services M&S community. The assessment has been achieved by identifying deficiencies in surveyed environmental capabilities to provide the data most needed by the DoD M&S community. The deficiencies, determined in the comprehensive analysis based on the information shown in the 25 figures, are summarized in Table 2. These deficiencies in capabilities, especially the major deficiencies, should be regarded as high priority areas for future atmospheric modeling and database development.

Recall that if some arbitrary range of fidelity requirements lacks any capability, thereby resulting in a fidelity gap, the capability is obviously deficient within that gap. In this analysis, only if more than 25 percent of the total requirements cannot be matched by capabilities, however, is the overall fidelity capability defined as deficient. The fidelity of a capability is said to "match" the fidelity of a similar requirement if the two fidelities differ by a factor of three or less. Furthermore, an environmental capability is defined as a major deficiency if more than 50 percent of the total fidelity requirements cannot be matched.

Table 2. Overall Deficiencies of Current Environmental Models and Databases

Primary Type of Atmospheric Data Required	Deficiency of Fidelity Capability (d) (D=Major Deficiency)		
	Horizontal	Vertical	Temporal
Aerosols	D	d	d
Clouds	d	d	
Fog	D	D	
Humidity	D	D	d
Precipitation	d		d
Temperature	d		
Visibility	D	D	d
Wind	d		d
Summary	4D/4d	3D/2d	5d

Table 2 summarizes the analysis and discussion in Subsection 3.2. An upper case D in an element of the table's matrix implies a major overall deficiency in capability to provide the specific type of atmospheric data; a lower case d implies a deficiency; and a blank entry implies a sufficient capability.

Note that all horizontal fidelity capabilities are deficient (eight of eight) and half (four of eight) are major deficiencies; slightly more than half the vertical capabilities are deficient, and they also represent a problem for the DoD M&S; and while none of the temporal capabilities are major deficiencies, more than half are deficient.

From the point of view of the DoD M&S community, the areas of future environmental modeling and database development deserving the highest priority are fog, humidity, visibility, and aerosols. Fog, high humidity (which is closely related to fog, of course), and aerosols strongly affect visibility, a critical environmental factor in military planning, training, and operations. Hence, the environmental capabilities needing the most attention from the R&D community are needed not only for M&S activities but also for operational military activities.

In Table 3 the analysis contained in Table 2 is expanded by dividing the fidelity range into three relative parts: high, mid, and low. In Table 3 high refers to the observation that a deficiency falls specifically within the high-fidelity range, mid refers to the middle of the fidelity range, and low refers to the relatively

Table 3. Deficiencies of Current Environmental Models and Databases Within Specific Fidelity Ranges

Primary Type of Atmospheric Data Required	Deficiency Range of Fidelity Capability (d) (D=Major Deficiency)								
	Horizontal			Vertical			Temporal		
	High	Mid	Low	High	Mid	Low	High	Mid	Low
Aerosols	D	d	d	D	D		D		
Clouds	D				D				
Fog	D		D	d	D				
Humidity	D				D		D		
Precipitation	d	d					D		
Temperature	D			d			d		
Visibility	D	D		D	D		D	D	
Wind	D						D		
Summary	7D/1d	1D/2d	1D/1d	2D/2d	5D		5D/1d	1D	

low end of the range of fidelity. An upper case D in an element of the matrix in the table implies a major deficiency in capability to provide atmospheric data across the specific range of required fidelity; a lower case d implies a deficiency with a given range of fidelity; a blank entry implies no deficiency, the capabilities sufficiently match requirements.

Obviously, major deficiencies in the capability to provide atmospheric data exist in the high-fidelity range frequently required by the DoD M&S community as well as in the vertical capabilities in the mid-fidelity range. Note the wide spectrum of deficient fidelity capabilities for aerosols and visibility. Table 3, therefore, reveals areas where environmental research is needed most and, similarly, where research is not needed (for example, low-vertical and temporal-fidelity capabilities are sufficient to satisfy requirements).

4.2 CONCLUSIONS

The analysis described here ties together the results from two related reports: "Natural Environmental Effects in Military Models and Simulations: Part I—A Survey of Requirements" by Piwowar et al. (1996) and "Natural Environmental Effects in Military Models and Simulations: Part II—A Survey of Capabilities" by Burgeson et al. (1996). These three reports should be useful to at least two DoD communities: the developers of models and simulations, who need access to better environmental data, and

the developers of environmental models and databases, who could use these results to determine where to focus their future research.

The obvious conclusion to be drawn from the comparative analysis of requirements and capabilities, described in Section 3 and summarized in Tables 1, 2, and 3, is that new environmental capabilities are needed, especially at high horizontal and vertical fidelity. This and other conclusions from Section 3 point out the need for specific environmental model and database development solidly supported by the survey.

Areas of needed environmental research are identified in Table 3. Specific environmental capabilities, each of which could satisfy several DoD M&S requirements are identified in Table 4. These capabilities should be regarded as those needed the most and needed now, not as the only required capabilities.

4.3 RECOMMENDATIONS

The authors recommend that more highly focused follow-on surveys be conducted on both M&S environmental requirements and environmental capabilities. The results of these studies are needed to further the refining process of the conclusions discussed above and the drawing of more extensive conclusions. For example, specific capabilities could be identified that would be best for a specific model or simulation, or necessary modifications could be identified that would improve the "fit" of the requirement and capability.

Table 4. Required New Environmental Models or Databases

Primary Type of Atmospheric Data Required	Needed Fidelity of Capability		
	Horizontal	Vertical	Temporal
Aerosols	1000 m	100 m	
Clouds		100 m	
Fog	100 m	100 m	
Humidity	100 m	100 m	15 min
Precipitation	500 m		
Temperature	100 m		
Visibility	100 m; 10 km	100 m	10 s
Wind	100 m		5 s

In addition, follow-on surveys need to ensure that the major DoD models and simulations, especially those affected by the near space environment, have been taken into account. Specific models and simulations that fail to properly consider environmental effects should be identified and provided with a "map" showing the way to required capabilities. Follow-on surveys are also needed to identify requirements for accuracy and an improved description of fidelity.

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